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Optimization of Machining Parameters in Electrical Discharge Machining (EDM) of 304 Stainless Steel

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Abstract

In this investigation, the effect of electrical discharge machining (EDM) parameters such as pulse-on time (T_{ON}), pulse-off time (T_{OFF}), Voltage (V) and Current (I) on material removal rate (MRR) in 304 Stainless steel was studied. The experiments are carried out as per design of experiments approach using L_9 orthogonal array. The results were analyzed using analysis of variance and response graphs. From this study, it is found that different combinations of EDM process parameters are required to achieve higher MRR for 304 Stainless steel. Signal to noise ratio (S/N) and analysis of variance (ANOVA) is used to analyze the effect of the parameters on MRR and also to identify the optimum cutting parameters. The contribution of each cutting parameters towards the MRR is also identified. The results from this study will be useful for manufacturing engineers to select appropriate EDM process parameters to machine Stainless steel 304.

Keywords: Metal removal rate (MRR); Taguchi method; 304 Stain less steel

1. Introduction

Electrical discharge machining (EDM) is a non-traditional, thermo electrical process, which erodes material from the work piece by a series of discrete sparks between the work and tool electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric. The main goals of EDM manufacturers and users are to achieve a better stability and higher productivity of the EDM process. As newer and more exotic materials are developed, and more complex shapes are presented, conventional

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machining operations continue to reach their limitations and the increased use of the EDM in manufacturing continues to grow at an accelerated rate.

Nomenclature
MRR Metal removal rate
T_{on} Pulse on time
T_{off} Pulse off time
V voltage
I current

Advanced machining processes (AMPs) are capable of drilling macro or micro holes with high aspect ratios in difficult to cut materials [1]. Among the various AMPs, electrical discharge machining (EDM) is quite common for producing small holes. EDM, sometimes referred to as spark machining, is a non traditional method of removing metal by a series of rapidly recurring discrete electrical discharges between an electrode (the cutting tool) and the work piece in the presence of a dielectric fluid. In EDM drilling process, EDM drilling of small holes is a well-established technique. Jeswani [2] drilled small holes ranging from 0.19–0.71 mm diameter in high carbon steel using copper wires. Jain et al. [3] described the effect of pulse time, diameter of tool and depth of penetration on technological characteristic of EDM drilling in high-speed steel. Wang and Yan [4] used rotary EDM concept to drill blind holes in Al2O3/6061 Al composite. Mohan et al. [5-6] studied the machinability of Al-SiC metal matrix composite by drilling holes using rotary hollow tube electrodes made of different materials. Asokan et al. [7] analysed the effect of EDM parameters on deep hole drilling of titanium alloy using copper electrode. Uno et al. [8] demonstrated that it is possible to drill high aspect ratio holes in silicon material by EDM. A new composite electrode, a metal rod enclosed in a dielectric fluid pipe was developed by Kumagai et al. [9] to prevent secondary side sparks for drilling narrow deep holes in steel block. Even though hole making by EDM is a common process not much work has been reported in the field of EDM drilling of 304 Stainless steel and no standard data on machining parameters is readily available for reference. In the present work is to analyse the effects of process parameters on the MRR. Finally, the process parameters are optimized to get the maximum material removal rate.

2. Experimental

2.1 Materials used

The work piece material used for the experiments was 304 Stainless steel. The Mechanical properties of 304 stainless steel are presented in Table 1.hardness value of the 304 Stainless steel was 35 HRc. The commercial EDM oil, IPOL spark erosion 450 (specific gravity 0.75, kinematic viscosity (at 40°) 23 cSt and dielectric strength 12 kV min) was used as a dielectric fluid.

Table 1.Mechanical properties of 304 stainless steel

Dencity kg/m^3	Elastic Modulus GPa	Coefficient of thermal expansion mm/m/°C)	Thermal conductivity W/m.k	Hardness HRC	Specificheat J/Kg.k
8000	193	17.8	16.2	40	500

2.2 Taguchi Methodology

Taguchi Method is a system of cost-driven quality engineering that emphasizes the effective application of engineering strategies rather than advanced statistical techniques [3]. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and find cost-effective, robust designs for large-scale production and the marketplace. Shop-floor techniques provide cost-based, real-time methods for monitoring and maintaining quality in production. Taguchi Methods allow a company to rapidly and accurately acquire technical information to design and produce low-cost, highly reliable products and processes. Its most advanced applications allow engineers to develop flexible technology for the design and production of families of high quality products, greatly reducing research, development, and delivery time.

Normally, the full factorial design would require 3^4=81 experimental runs. However the effect and experimental cost for such a design may prohibitive and unrealistic. In this study Taguchi method a powerful tool in parameter design is used. According to the Taguchi quality design concept, L_9 orthogonal array with 9 rows (corresponding to the number of experiments) are used for the experimentation. It provides a simple, efficient and systematic approach to optimize the design for performance, quality and cost. The methodology is valuable when design parameters are qualitative and discrete [13]. Table 1 show four EDM parameters used as control factors and their levels. MINITAB 15 software is used for graphical analysis of the experimental data.

Table 2. Control parameters for EDM

Sl.No	Symbols	Cutting Parameters	Levels			Units
			1	2	3	
1	Ton	Pulse on time	40	50	60	μ Sec
2	Toff	Pulse off time	8	12	16	μSec
3	V	Voltage	50	100	150	volts
4	I	Current	20	35	50	amps

2.3. Selection criteria's for orthogonal array.

The conditions for selection of orthogonal array used in the experiment are

Degree of freedom (DOF) for factors : levels – 1.

DOF for OA : No. of trail – 1.

DOF of L9 orthogonal array : 9 – 1 = 8.

The orthogonal array is selected based on the following conditions.

$\sum DOF_i \leq$ DOF of OA, number of factors : i = 1 to n.

2.4 Experimental procedure.

The experiments were conducted using a ram EDM machine, model C-425 manufactured by Electronic Industries, India. The electrode is fed downwards into the workpiece under servo control in this EDM machine. A special rotary head has been fabricated and attached to the quill of the EDM machine to provide rotary motion to the electrode. The electrode-rotating device consists of a precision spindle, a timer belt drive mechanism, and a speed control unit. The spindle was designed with built-in seals to effect flushing through the electrode. Figure 1 depicts the photograph of experimental setup used for the experimentation. Before experimentation, the workpiece top and bottom faces were ground to a good surface finish using a surface grinding machine. The bottom of the tube electrode is polished using a very fine grade emery sheet before every experiment. The initial weight of the work piece was weighed using a 1 mg accuracy digital weighing machine. The work piece was held on the machine table using a specially designed fixture shown in Fig. 1. The work piece and tool were connected to the negative and positive terminals of power supply, respectively. The dielectric fluid was flushed at a pressure of 2 kgf/cm2 through the tube electrode. Holes of 3 mm depth were drilled in all the experiments. The time taken for machining a hole was recorded using an electronic timer. The completion of hole was signalled by the emergence of the dielectric jet through the bottom of workpiece. The experiments were conducted in a random order so as to remove the effects of any unaccounted factors. End of each experiment, the work-piece was removed from the machine, washed, dried, and weighed on an electronic balance. The material removed rate was calculated using the following formula:

$$MRR = \frac{\text{Intial weight of workpiece} - \text{Final weight of workpiece}}{\text{Machining time}} \text{ mg/min} \qquad \text{------------------- (1)}$$

The experimental results are presented in Table 3.

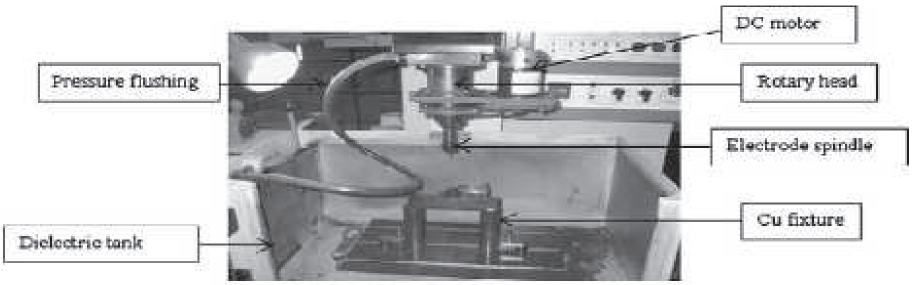

Figure 1 Photograph of Experimental setup.

Table 3. Experimental results.

Experiment No.	Pulse On time (T on)		Pulse Off time (T off)		Voltage(V)		Current(I)		MRR
	Coded	Actual	Coded	Actual	Coded	Actual	Coded	Actual	(gms / min)
1	1	40	1	8	1	50	1	20	19.49
2	1	40	2	12	2	100	2	35	25.24
3	1	40	3	16	3	150	3	50	18.42
4	2	50	1	8	2	100	3	50	13.49
5	2	50	2	12	3	150	2	20	16.03
6	2	50	3	16	1	50	1	35	36.56
7	3	60	1	8	3	150	2	35	19.96
8	3	60	2	12	1	50	3	50	28.37
9	3	60	3	16	2	100	1	20	15.38

3. Results and Discussions

The selected four parameters have different influences on the machining performance. The significant parameters are found by the analysis of variance (ANOVA) and the optimal cutting parameters are obtained using the main effects plot.

The characteristics that higher values represent better machining performance such as material removal rate is called "higher is better (HB)" in quality engineering. The S/N ratio (signal to noise) could be an effective representation to find the significant parameter by evaluating the minimum variance. The equation for calculating the S/N ratio is

"Higher is Better"(HB) S/N ratio = $-10 \log (1/r (1 / y_1^2+y_2^2+y_3^2+\ldots\ldots\ldots.y_n^2))$-----(2)

By applying these equations, the S/N values of machining performance for each experiment of L_9 OA can be calculated for the MRR values and it is presented in Table 4. In order to obtain the effects for machining parameters for each level, the S/N values of each fixed parameter and level in each machining performance is summed up.

Table 4. Experimental Results with S/N Ratio for Material Removal Rate.

Exp. No.	Material Removal Rate (gms / min)	S/N Ratio
1	19.49	25.7962
2	25.24	28.0418
3	18.42	25.3058
4	13.49	22.6002
5	16.03	24.0987
6	36.56	31.2601
7	19.96	26.0032
8	28.37	29.0572
9	15.38	23.7391

From the calculation of main effects for each level of the factors, the main effects values are presented in Table 5. The main effect values and interactions are plotted in Figure 2 &3 for factors pulse on time, pulse off time, voltage and current respectively. The main effects plot shows the influence of each level of factors on the machining performance. The levels having the major contribution are selected from the plot and are the optimized levels for the particular factor.

Table 5.Response Table for Signal to Noise Ratios.

Level	Pulse On time (T on)	Pulse Off time (T off)	Voltage	Current
1	26.38	24.80	28.70	24.54
2	25.99	27.07	24.79	28.44
3	26.27	26.77	25.14	25.65
delta	0.39	2.27	3.91	3.89
Rank	4	3	1	2

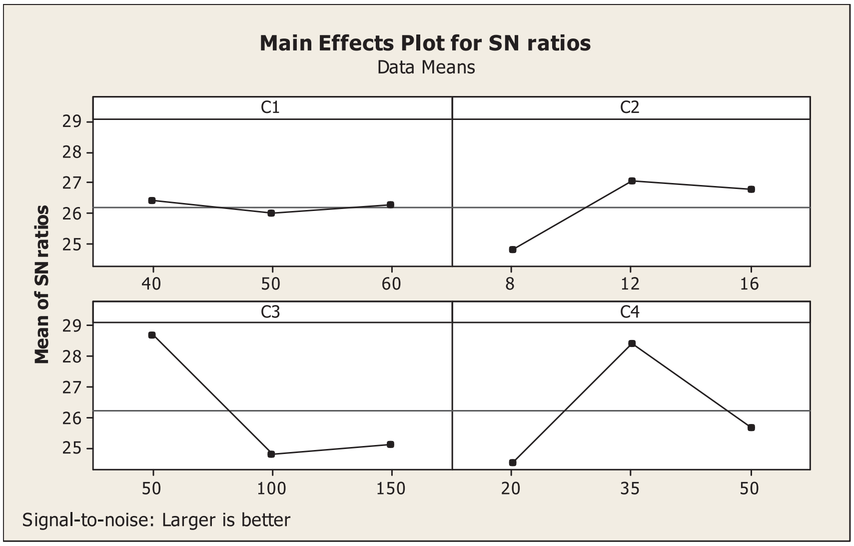

Figure 2. Response graph for S/N Ratios.

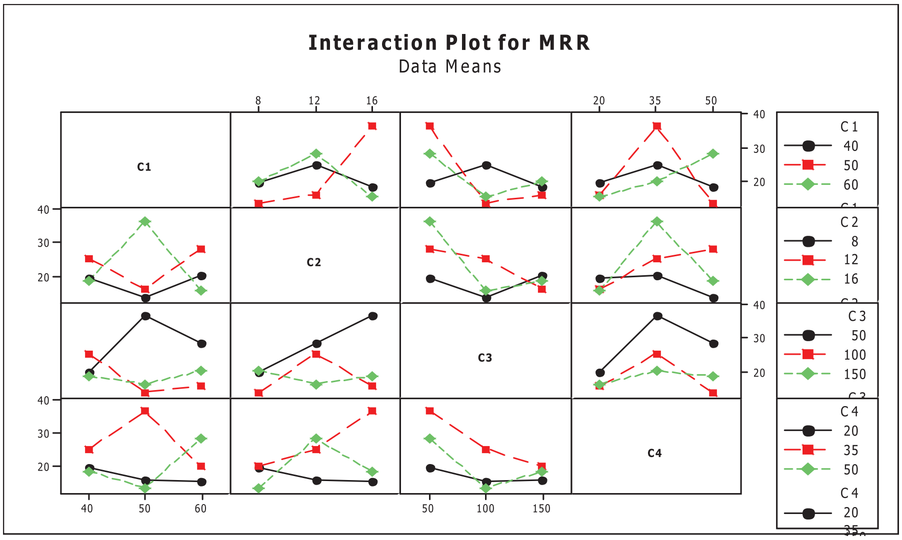

Figure 3.Interaction plot for MRR

The relative importance of the cutting parameters with respect to the MRR is investigated by analysis of variance (ANOVA). Tables 6 give the ANOVA results for MRR. From the analysis of Table 6, it is observed that the pulse off time (43%) and current (33%) have statistical significance on the MRR.

Table 6.ANOVA for MRR

Source	Sum of Squares	df	Mean Square	% of contribution
Pulse on time (Ton)	22.91	2	11.45	5.26
Pulse off time (Toff)	191.07	2	95.5	43.88
Voltage(V)	77.34	2	38.75	17.76
Current(I)	144.05	2	72.01	33.08

Thus, by utilizing experiment results and computed values of the S/N ratios, average effect response value and average S/N response ratios are calculated for MRR and presented in Table 4. The S/N ratio response graph for MRR is shown in Figure 2. Regardless of category of the performance characteristics, a greater S/N ratio value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest S/N ratio value. Based on the analysis of S/N ratio, the optimal machining performance for the MRR is obtained at a pulse on time of 40 μs (level 1), pulse OFF time of 12 μs (level 2),voltage of 50V (level 2) and current of 35 amps (level 2).

4. Conclusion

On the basis of experimental results, calculated S/N ratio, analysis of variance (ANOVA) and 'F' test values, the following conclusions are drawn for EDM of 304L stainless steel.

- The current and pulse OFF time are the most significant machining parameter for MRR in EDM of 304 stainless steel.
- For higher material removal rate, the recommended parametric combination is pulse on time at level 1, pulse off time at level 2,voltage at level 2 and current at level 2. for EDM of 304 stainless steel.
- Based on the minimum number of trails conducted to arrive at the optimum cutting parameters, Taguchi method seems to be an efficient methodology to find the optimum cutting parameters.

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